Modulation of Short Wind Waves by Long Waves and Effects on Radar Reflectivity

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LONG-TERM GOALS

- To determine the effect of long waves on the modulation of short waves in various levels of wind forcing.

- To isolate and quantify the effects of the modulation of the short waves on the radar reflectivity.

OBJECTIVES

- To complete the analysis of an extensive data set on the modulation of short wind waves by long waves. The experiments were done in collaboration with Dr. William Plant (APL, U. of Washington) in the RSMAS Air-Sea Interaction Saltwater Tank (ASIST) facility. *(Year 1)*

- To conduct and analyze additional experiments in the RSMAS ASIST facility to clarify any issues that arise from the analysis of the existing data. These experiments will employ enhanced and innovative measurement techniques that were not available for the first set of experiments. *(Year 2 experiment, Year 3 analysis)*

- To relate these measurements to expected results in field conditions. *(Year 3)*

APPROACH

To determine the effect of long waves on the modulation of short waves and the effect that this modulation has on radar reflectivity, a series of laboratory measurements has already been conducted and additional measurements will be collected through this project. The wind-wave tank at the Canada Centre for Inland Waters (CCIW) and the Air-Sea Interaction Saltwater Tank (ASIST) facility at the University of Miami were used for the preliminary experiments discussed here. The ASIST facility will be used for the upcoming experiments in FY03 and FY04. A significant component of the effort in Year 2 was devoted to improving the capabilities of the ASIST facility to precisely measure surface slopes. A new wave slope collection device has been designed and fabricated for installation in ASIST. In addition an innovative technique has been developed through this project to enhance the accuracy of

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the optical Imaging Slope Gauge (ISG). With these improvements ASIST provides a unique opportunity for all of the critical parameters for the modulation of radar reflectivity to be directly observed.

WORK COMPLETED

A series of experiments to study the modulation of short waves by longer waves including wind forcing was conducted at the Canada Centre for Inland Waters (CCIW) and at the ASIST facility. In addition innovative slope measurement, techniques have been developed and tested in ASIST for application to the modulation measurements to be conducted at the beginning of Year 3 of this project.

CCIW experiments
These experiments were conducted in a 32 m long-wind wave tank with a Ku-band dual polarized (VV and HH) radar at a fetch of 14 m. At the same location a single laser beam intersected the surface from below. The water (of depth 22.5 cm) contained a small quantity of fluoroscein, which was excited by the 488 nm laser beam. The elevation information was captured by a line-scan camera, as described above, while the emergent refracted beam was captured on a large Fresnel lens above the tank. The focused beam was detected on a 4-port position detector, allowing local surface slope measurements to be made at rates up to 1000 Hz. These local elevation and slope measurements are combined in the Wavelet Directional Method (Donelan et al., 1996) to yield instantaneous information on the distribution of wave energy among various wavenumbers.

ASIST experiments
The first set of experiments in the ASIST facility was conducted in February 2001. C-band (upwind) and Ku-band (downwind) dual polarized Doppler radars illuminated the water surface at an incidence angle of $\pm 45°$. Within the radar footprint three laser elevation sensors were positioned in a triad with spacing between beams of 1-cm to precisely determine the two components of the surface slope at a rate of 500 Hz. The near-surface air and water velocities and turbulence were measured using thermal velocimetry and a digital Particle Image Velocimeter (PIV).

The wind forcing was varied over a range of 0-15 m/s measured at the centerline of the tank. Monochromatic long-waves were generated with frequencies from 0.1 Hz to 1.0 Hz and with maximum slopes from 0.05 to 0.3. For each run the time-varying Doppler backscatter was observed with the radars. The upwind and crosswind slopes were simultaneously sampled for runs of duration 262 seconds. This run length provided reliable statistics for the relationship between local wave slopes and the radar backscatter.

The second set of experiments in the ASIST facility was conducted in June, 2001. An imaging slope gauge (ISG) was installed and calibrated. ISG images were collected at a rate of 120 Hz. The two-dimensional distributions of surface slopes were observed at the same location that was simultaneously sampled with the C-band Doppler radar. Observations were limited to 4 second duration.

Improvements to wave slope measurements
The directional wave spectrum during the first set of experiments was remotely sampled using a triad of laser elevation sensors. An Argon-Ion (488 nm wavelength, 150 mwatts) air-cooled laser equipped with beam splitters and mirrors provided 3 vertical beams in an equilateral triangle of side 1 cm at any point in the tank. The intersection of these beams with the surface was detected by line-scan cameras

at a rate of up to 250 Hz. This permits the detection of slope of waves of 2 cm and longer. The cameras have a dynamic range of 2048 (pixels) and the range of heights was determined by the choice of lenses. This technique will continue to be used to measure the wave elevation, but the Nyquist wavenumber is too close to that of the Bragg scatterers at Ku-band and another slope measuring method is planned. In future a laser collection device that samples the deflection of a single beam will be used to determine the surface slope. Thereby enabling the elevation and slope to be determined at a single point. This instrument has been designed, fabricated and calibrated and will be installed in ASIST for the Year 3 measurements.

The initial series of measurements were conducted in the ASIST facility with the Imaging Slope Gauge configured to use a light source underneath the tank that shone through a mask with a specified color gradient. The mask was viewed through a Fresnel lens that focused all light that penetrated the surface at the same slope on the same point of the mask, thereby identifying slope with color. A pair of RGB video cameras directly observed the two components of the water surface slope through the relative intensities of the color components at each point of the mask. The ISG imaged an area of the water surface of up to 45 cm (downwind) x 30 cm crosswind at a pixel resolution of 640x240. This corresponded to a spatial sampling area on the water surface of 0.07 cm x 0.12 cm. The sampling rate using both cameras was as high as 120 Hz. The alongtank and crosstank slopes were then obtained through a careful calibration with an acrylic box held at known angles. As in previous slope measurements obtained in other wind-wave facilities the method was significantly (20-30%) limited by mask imperfections, light intensity variations and cross-talk between color components. To reduce this noise an innovative projection technique was conceived, developed and implemented through this project that enabled us to improve the characteristics of the ISG measurements.

This technique takes advantage of advances in LCD projection to produce the color gradients using a digital image. An image with known gradients in blue and green intensity was projected onto a white screen underneath a test section of the tank. This digital image was recorded by the RGB cameras, and then used to correct the input image on a pixel-by-pixel basis. This allowed the mask to be precisely tailored to produce linear and orthogonal gradients of color. The resulting slope observations had significantly less noise and will allow for much more precise determination of the short wave modulation (Figure 1). In addition to the improvement in the measurement accuracy, new image acquisition hardware and software have been installed that will allow much longer experimental runs in order to improve the statistics of comparisons between the surface slopes and the radar backscatter.

RESULTS

Analysis of the two sets of experiments conducted at CCIW and in the ASIST facility have revealed that there is a different relationship between short surface wave energy at Bragg wavenumbers and long-wave phase at low and high wind speeds. The low wind speed data was discussed in the Year 1 report; it showed that peaks in Bragg-wavenumber scale at low winds (1.8-3.2 m/s) most often associated with leeward face of long wave. The higher wind speed measurements (12.5 m/s) in the ASIST facility showed that the wind-wave structure was strongly impacted by the presence of long-waves (1 Hz) as at lower winds (Figures 1,2). The wind waves shifted frequency to become phase locked with the long waves and have become more aligned with the long waves. Peaks in Bragg-wavenumber scale at higher (12.5 m/s) winds most often associated with transition between negative and positive slopes (i.e., crests) of long waves. Longer time-series of modulation runs are necessary to establish reliable phase-averaged estimates. The C-Band Doppler spectrum was strongly modulated by

the long wave with the peak returns shifted to higher frequencies (Figure 3). Differentiation of the effects of hydrodynamic and tilt modulation will be facilitated by the enhanced measurement of local slopes to be employed in the Year 3 experiments.

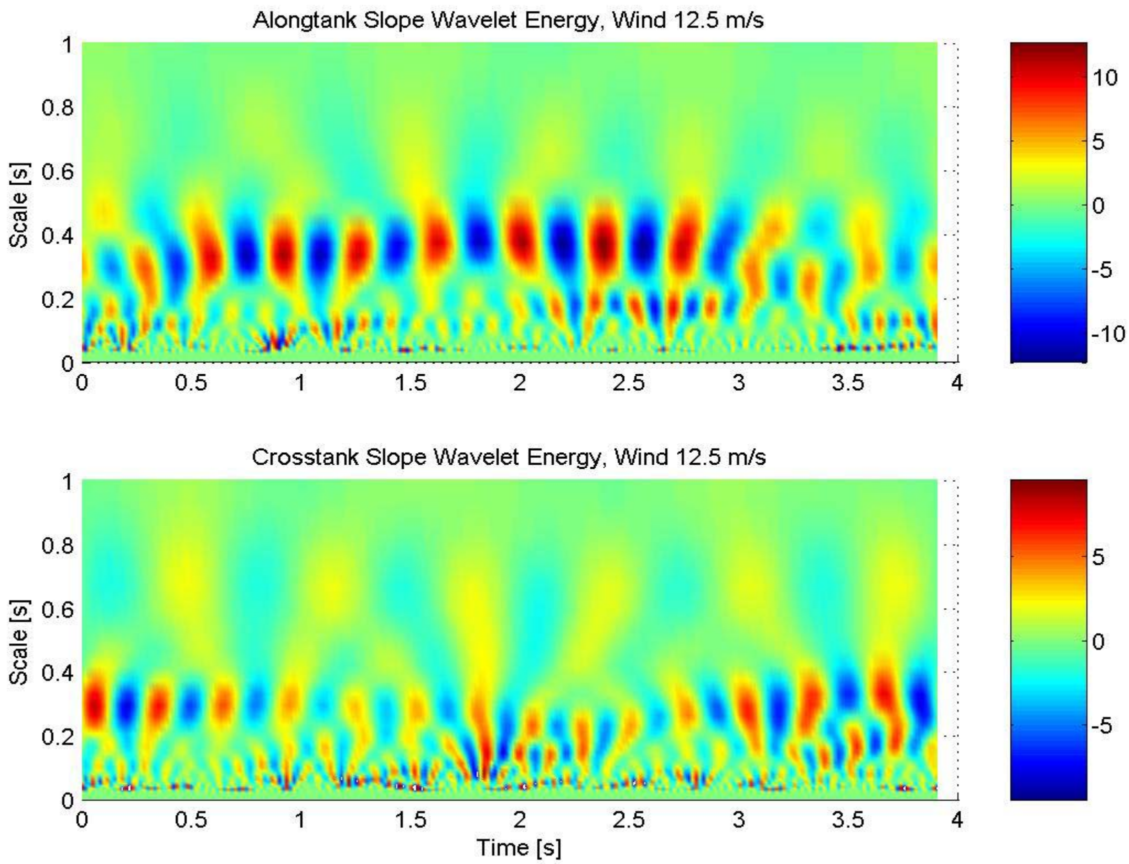

Figure 1. Morlet wavelet spectrum of wind generated waves, Wind velocity 12.5 m/s. Top plot alongtank energy, bottom plot cross-tank energy. Scale is proportional to wave period. Dominant wind waves are centered at 0.3 s. Bragg waves are at scales less than 0.1 s. Positive energies denote increasing slopes, Negative energies denote decreasing slopes.

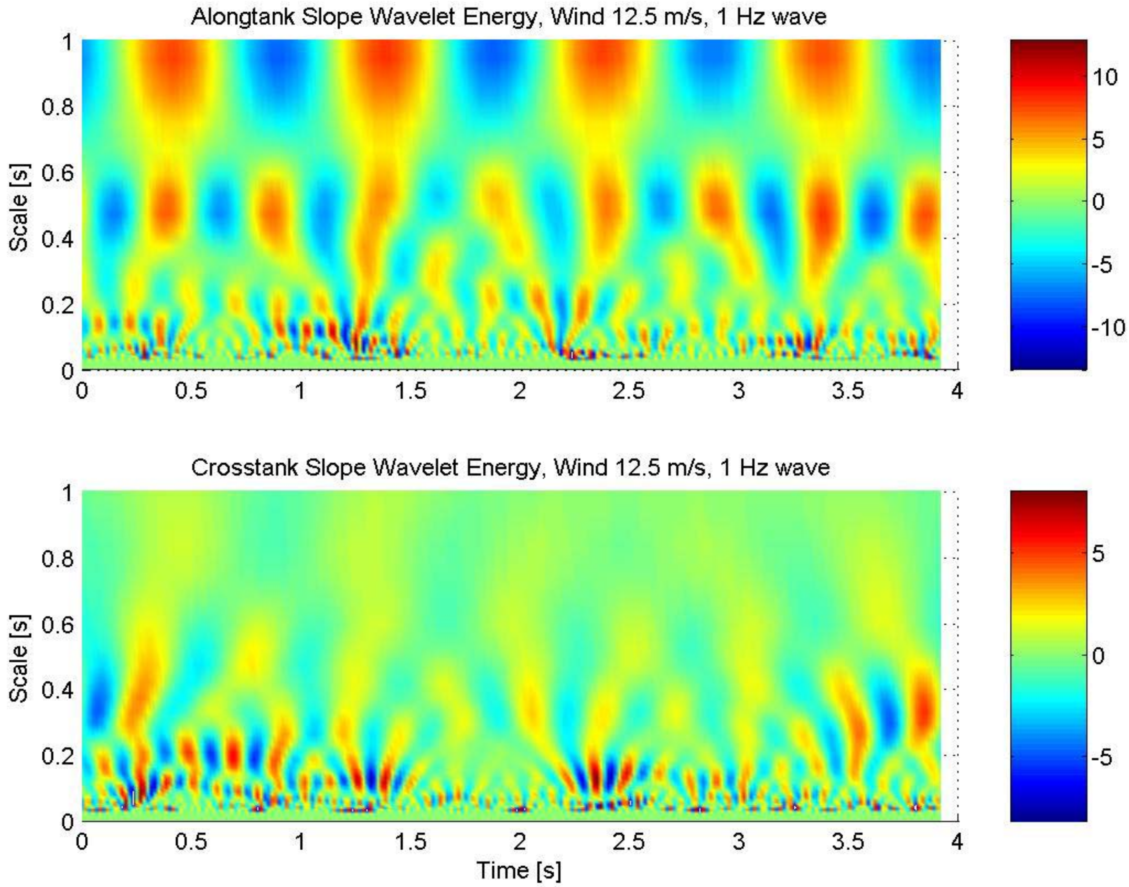

Figure 2. Morlet wavelet spectrum of wind generated wave slope, Wind velocity 12.5 m/s combined with a mechanical wave with frequency 1 Hz. Top plot alongtank energy, bottom plot cross-tank energy. Scale is proportional to wave period, 1Hz mechanical wave has 1 s scale, dominant wind waves are centered at 0.3 s. Bragg waves are at scales less than 0.1 s. Positive energies denote increasing slopes, Negative energies denote decreasing slopes.

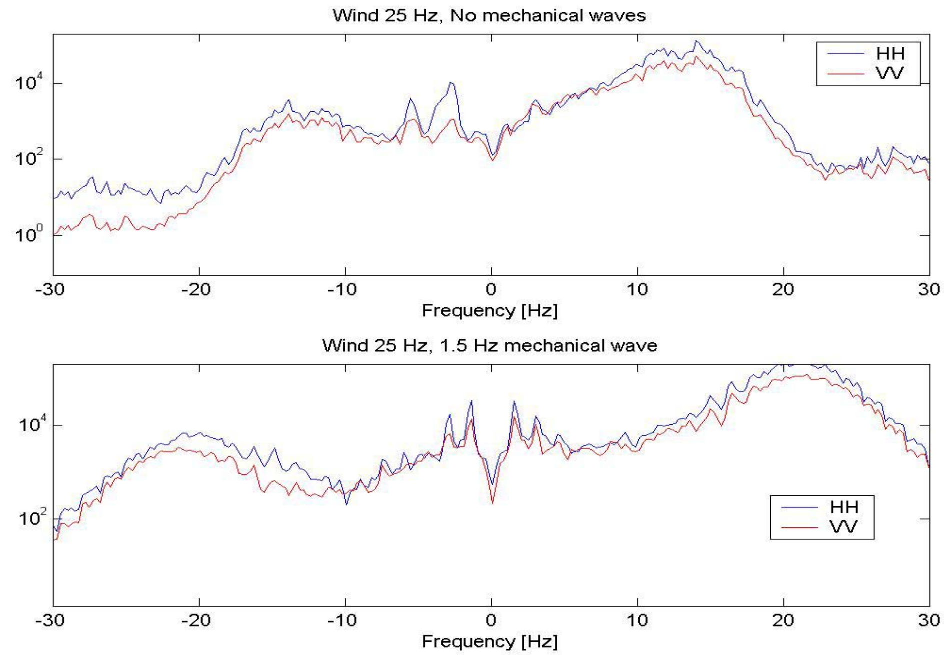

Figure 3. C-band radar echo Doppler spectrum for upwind looking radar for wind as shown in previous figures. Top plot Wind 25 Hz without mechanical waves. Bottom plot, wind 25 Hz with 1.5 Hz mechanical wave. Radar angle at 45 deg. to the surface.

IMPACT/APPLICATIONS

This project is focused on basic improvements to the modulation transfer function that allows radar backscatter to be related to ocean surface wave properties. Advanced techniques are applied to make radar and wave measurements that are collocated in both space and time without disturbing the wave field. This will provide the necessary data to validate and improve expressions for the transfer function. The improved formulation can then be used to estimate surface wave properties from space or airborne radars.

RELATED PROJECTS

"Bound Waves and Microwave Backscatter from the Ocean"; William J. Plant (P.I.); ONR Grant # N00014-00-1-0075.

REFERENCES

Donelan, M.A., W.M. Drennan and A.K. Magnusson, 1996: Non-stationary analysis of the directional properties of propagating waves. J. Phys. Oceanogr. 26, 1401-1414.

PUBLICATIONS

Haus, B. K., M. A. Donelan and W.J. Plant. 2003. Optical Measurements of the Modulation of Short Wind Waves by Long Waves and their Effect on Observed C-band Radar Reflectivity. *Geophysical Research Abstracts*, Vol. 5, 11426. European Geophysical Society.